# Research overview

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# Purpose

The EMC related work at De Montfort University falls into the inter-related groups of:

- Electromagnetic simulation, measurements, objective/quantification comparison
- Transmission lines
- Communications channel physical layer
- EMC and signal integrity, noisy environments

This talk will look at some specific aspects of the first and last of these bullets.

# Content

- Ethernet susceptibility
- Data comparison using FSV

# The fourth utility

Cisco have proposed that communications infrastructures will become "*the fourth utility – an integral part of the building itself and as relevant as water and electricity and gas. In fact, all building systems will converge onto one building communications infrastructure based on the IP protocol*"

Now more than ever, this holds true.

*Source: David Barry, News@Cisco, August 23rd 2007*

# IoT

- Vast majority of IoT application require twisted pair Ethernet somewhere
- PoE is a significant enabler – as is energy harvesting
- Understanding coupling from external noise very important

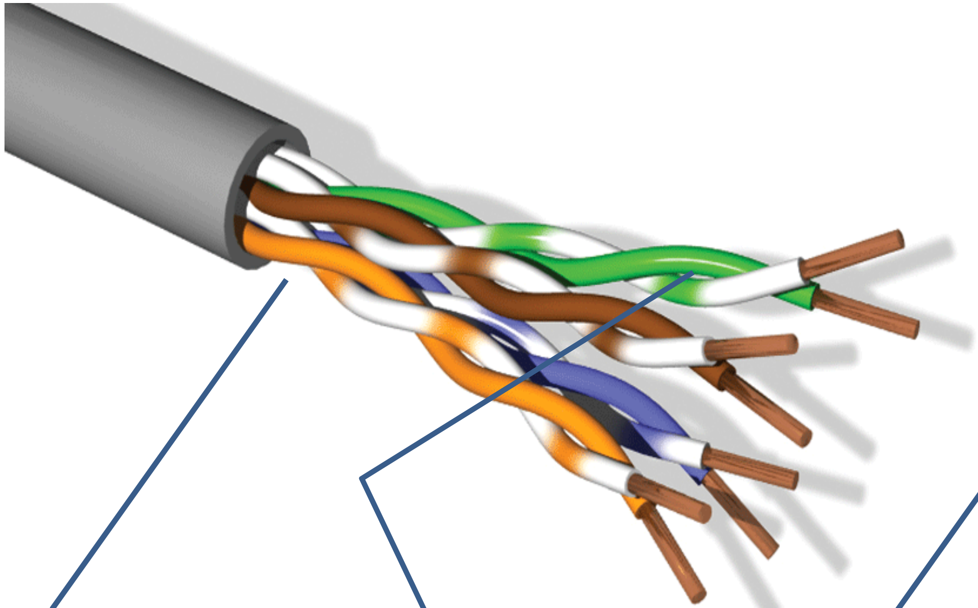
# Where do we find Ethernet

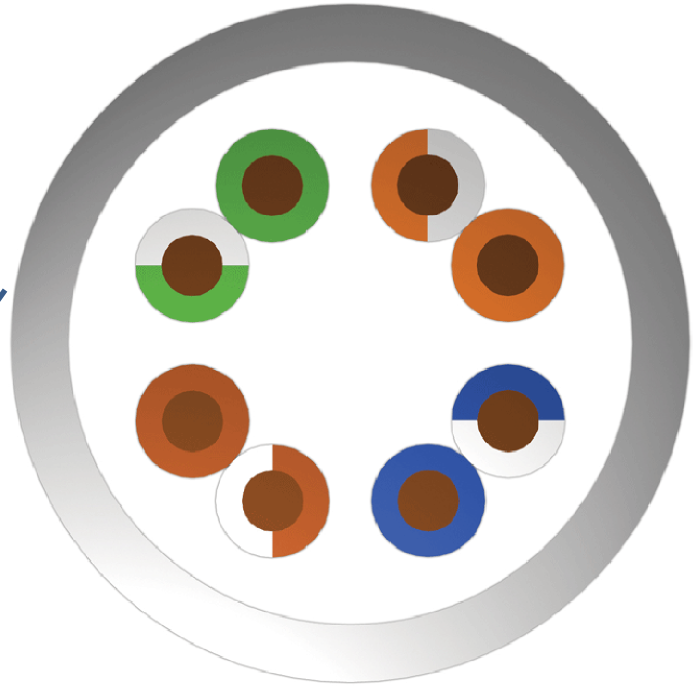
- Created in 1973, introduced in 1980 at Xerox for computer-computer communications.
- Everywhere in commercial buildings / industrial installations
- Backhaul for4G/LTE services
- Smart Grid communications
- Remote powering
- IoT is a catch-all term for interconnected machine-to-machine networks of smart devices.

http://electronicdesign.com/communications/ethernet-evolves-again-meet-internet-things

# Twisted pair

- For the uninitiated:





Four balanced pairs

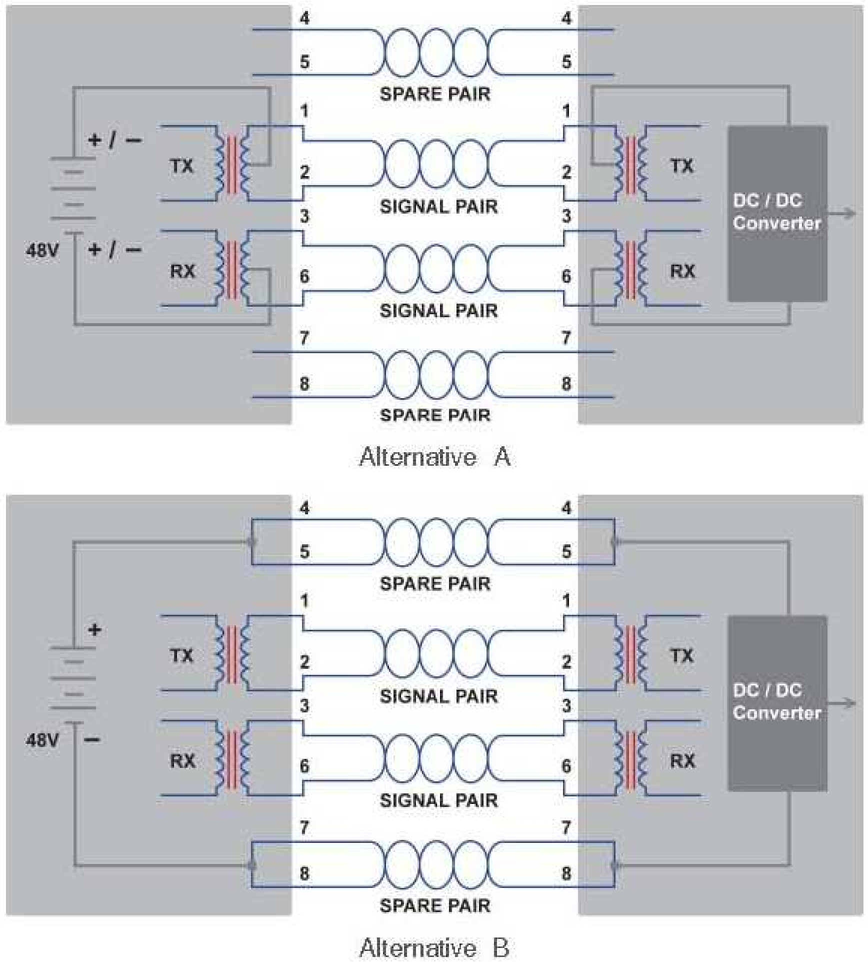
Each with a different lay length – may have a shield

May or may not have a shield

Pictures courtesy of Brand-Rex Ltd

# Powering PoE

Phantom powering – also allows for 10GBaseT operation and the method allows for four pair powering




Power sourcing equipment (PSE) Powered Device (PD)



Figure © Korenix Technology Co Ltd

# Speeds

The benefits of using these higher bandwidth channels is fairly self evident:

| Link Speed | 100M | 1G | 10G | 100G |
|---|---|---|---|---|
| **Time to transfer 30GB MRI image** | **40min** | **4min** | **24sec** | **2.4sec** |
| **Time to back-up 2TeraB memory** | **2.2day** | **4.5hrs** | **27min** | **2.7min** |

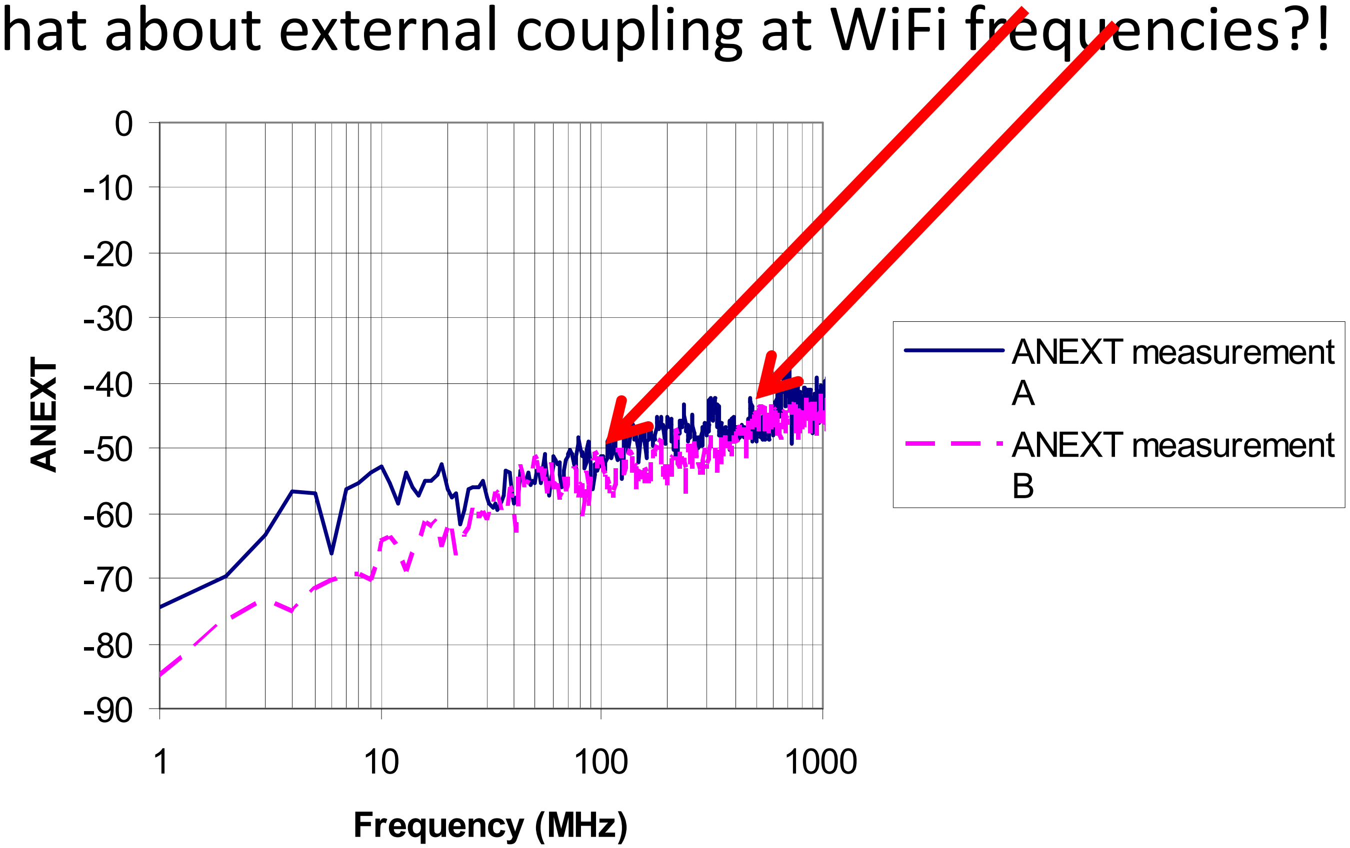
Data courtesy of Brand-Rex Ltd

# ANEXT

- Noise from other cables.
- Assumes that the six nearest will make the major contribution (cf interference from mobile base stations)
- Power sum rather than voltage sum used
- Frequency dependent – more of an issue for the higher frequency cables.

# ANEXT

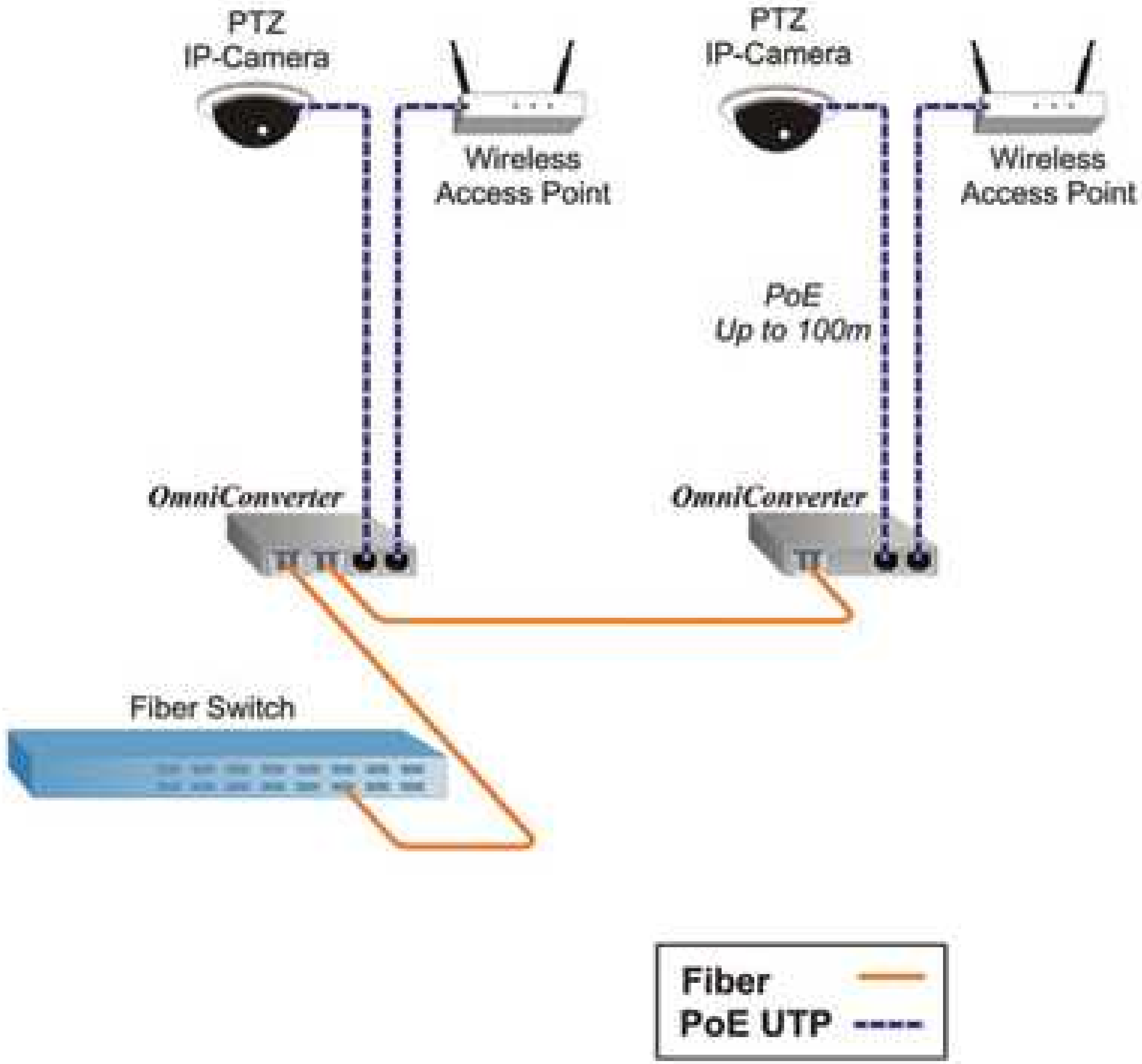
- Can see how much the problem increases as a function of frequency  - very approx 4x increase from 100MHz to 500 MHz!
- So what about external coupling at WiFi frequencies?!



# EMC and wireless access points

- New standards are being introduced for 2.5Gbps and 5Gbps for Wireless access points.
- Given that many organisations will want to use existing infrastructure or cheap Category 5 or possibly the more expensive Category 6 cables, it is worth asking what the magnitude of the problem of coupling into the Ethernet cable might be and if there is a marked benefit in investing in Cat. 6

# Representative installation




*Picture taken from google images*

# Comparing CAT 5e and CAT 6

- **CAT 5e**
- **Speed**- 1000Mbps
- **Cost**-Varies by length and manufacturer, generally $0.20 - $0.30 per foot.
- **Frequency -**Up to 100MHz
- **Performance-**Less crosstalk/interference than CAT5. Potentially more interference than CAT6.
- **Maximum Cable Length-**100 meters

- **CAT 6**
- **Speed** -10 Gbps over 33-55 meters (110-165 feet) of cable
- **Cost**-Varies by length and manufacturer, with $0.40 - $0.60 per foot as an average; generally about 20% higher than Cat5e
- **Frequency-**Up to 250 MHz
- **Performance –** Higher SNR
- **Maximum Cable Length -** 100 meters for slower network speeds (up to 1,000 Mbps) and higher network speeds over short distances. For Gigabit Ethernet, 55 meters max, with 33 meters in high crosstalk conditions.

# Experiment setup

Chamber size: 5m x 3m x 2.3m with a single stirrer of two vanes which are 1m square attached to a vane shaft at 45 degree to the vertical.

Frequency range- 100KHz-6GHz

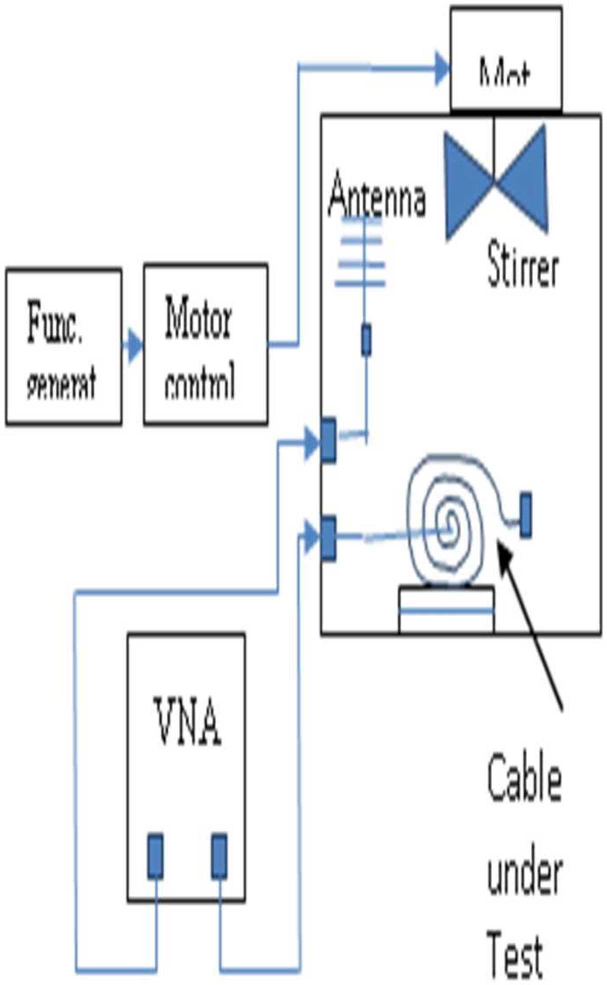
Mode tune operation was used.

Transmitter antenna excited the chamber.

Receive antenna measured the generated field.

VNA was used to measure the coupling between the transmit antenna, the receive antenna and the twisted pair under test.

A function generator selected the square wave pulse that drove the control motor.

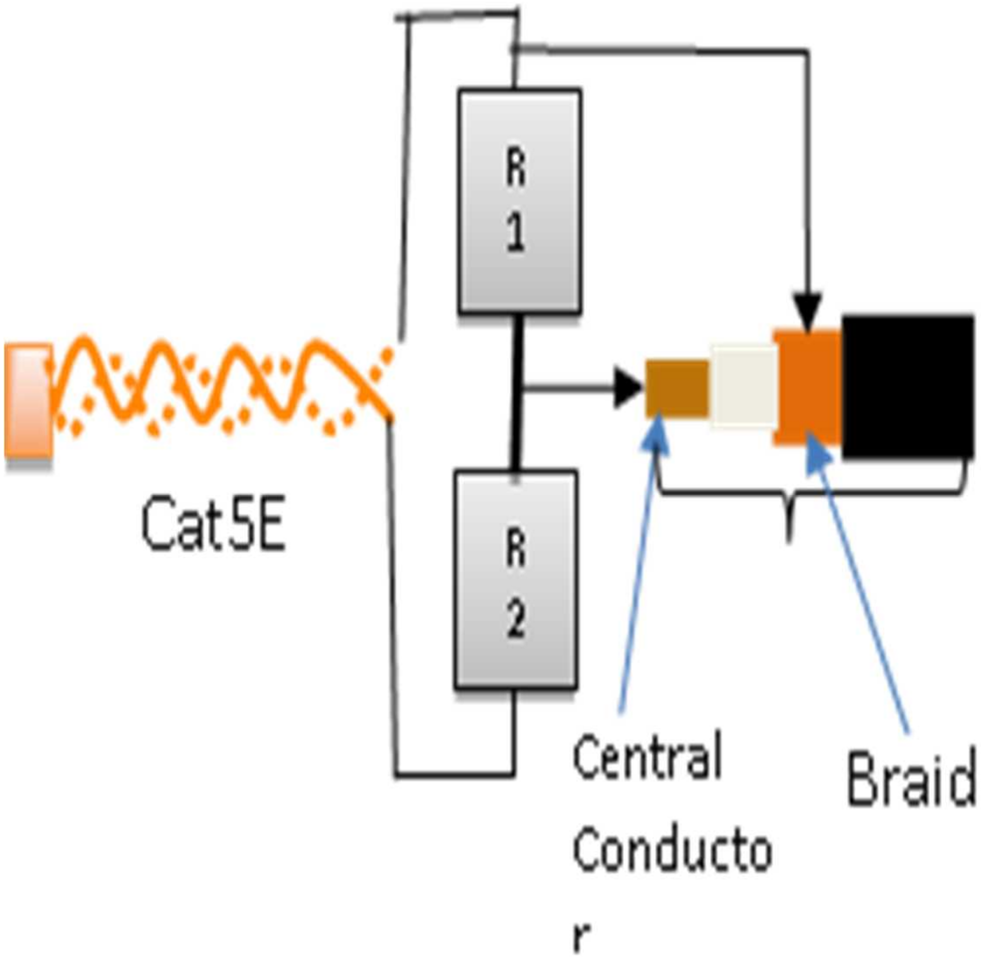


# Test Procedure

The far end of the cables were terminated in 100 ohms pure resistive loads

The near end was connected through a voltage divider network to the vector network analyser

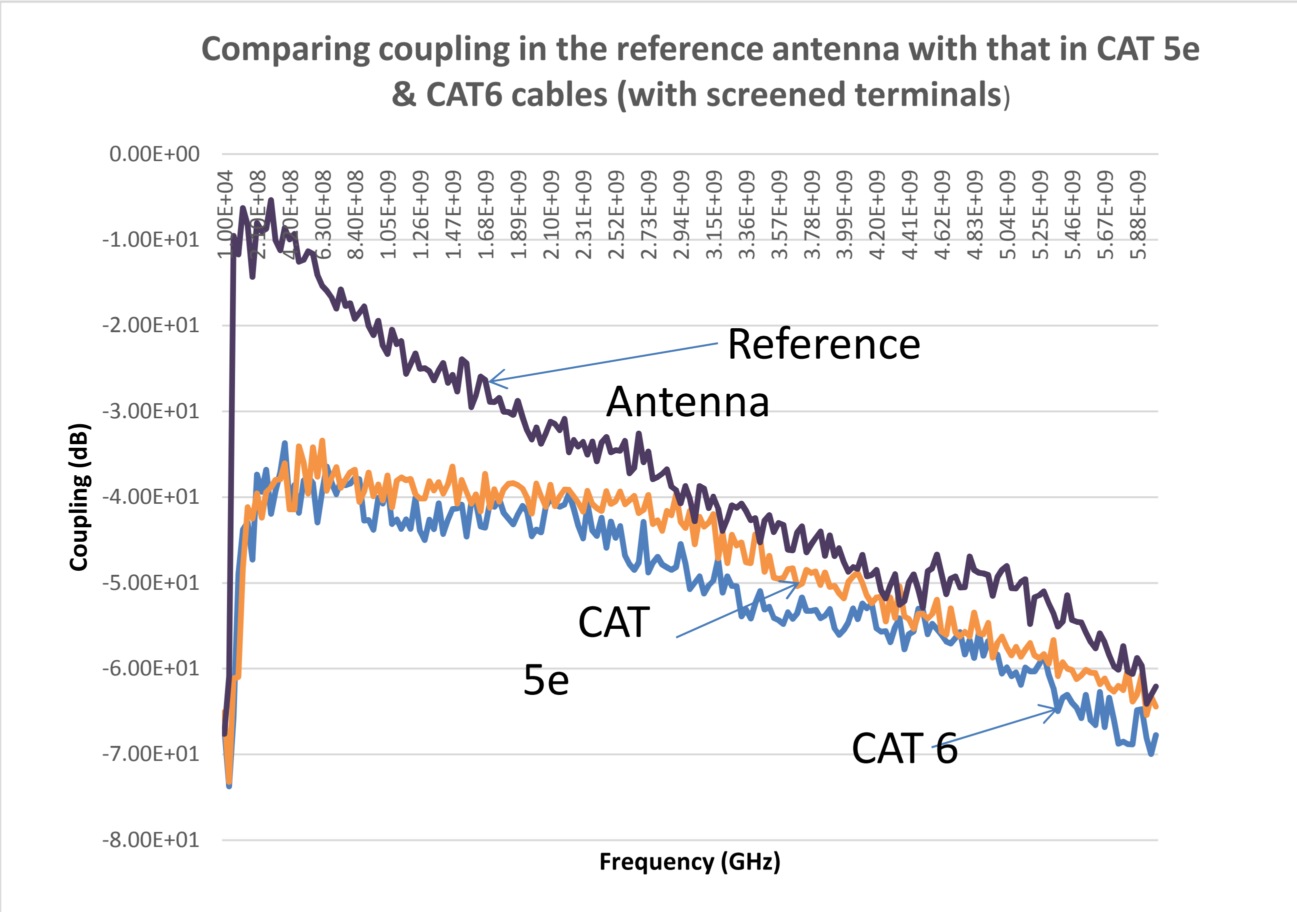
N-to-BNC connectors were used to link the VNA through the chamber wall and the cable under test using a 50 ohm coaxial cable.



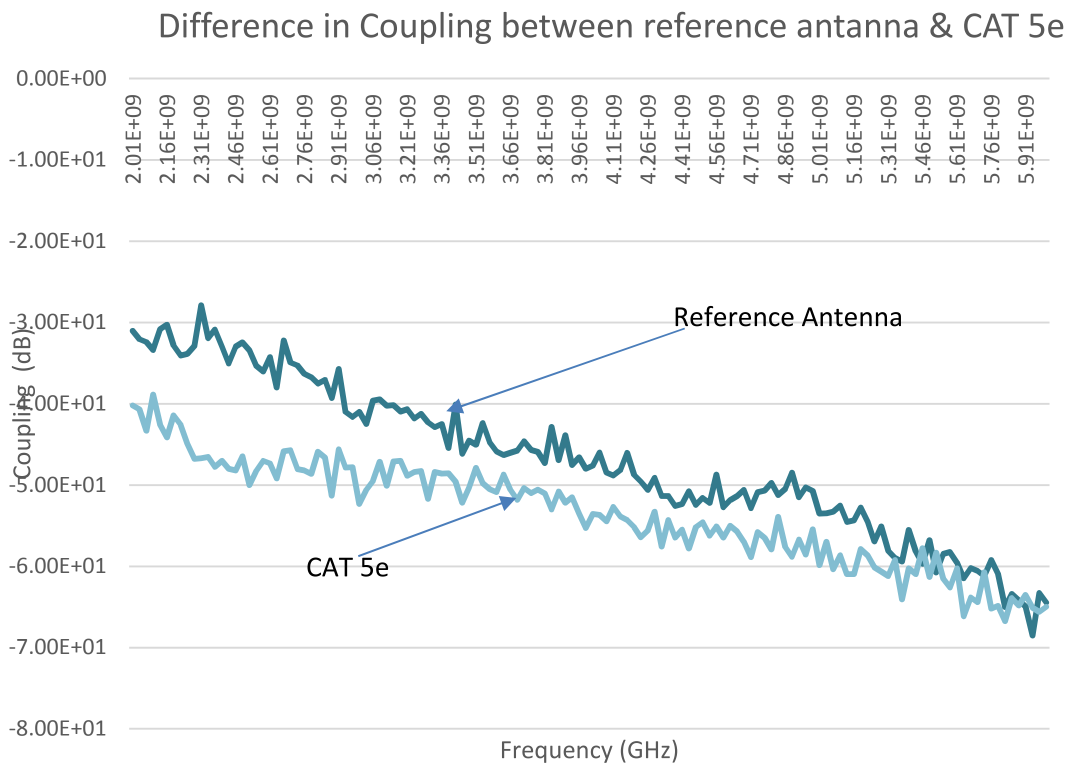
# A note on the measurements

- For this experiment, we were only interested in single ended data to provide a reference comparison.
- Mixed mode results could be obtained to get a better picture of both common and differential mode coupling.

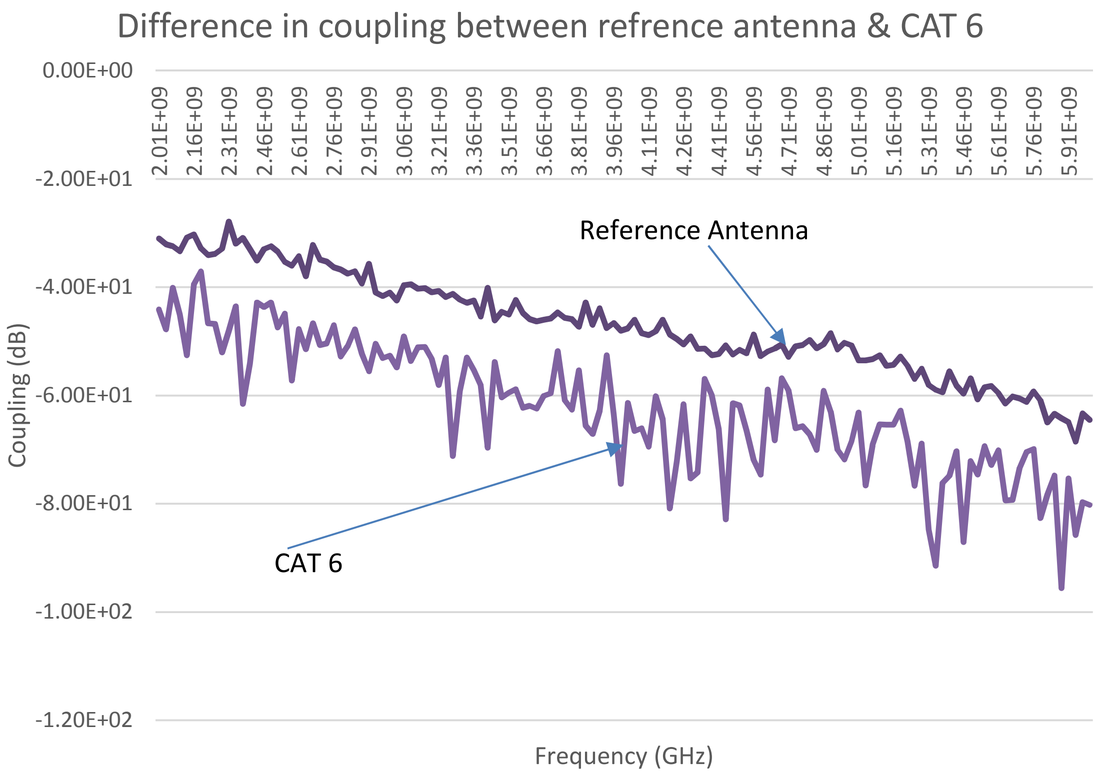
# Comparing coupling in reference antenna with that in CAT 5e & CAT6 (screened)



# Coupling between reference antenna & CAT 5e from 2GHz to 6GHz



# Coupling between reference antenna & CAT 6 from 2GHz to 6GHz



# Coupling to cables

- There is a notable difference between the cables
- Current research is looking at how much that might be troublesome to connected equipment and what limitations might need to be imposed on the use of various categories of cables.

# Data comparison

- EMC and related data is notoriously difficult to compare.
  - Comparing measurements
  - Comparing simulations
  - Comparing measurements with simulations
  - Relative comparison of comparisons
  - Line data, surface and volumetric data, “hyper surface” and “hyper volume” data

# The method being discussed

- The next section of this talk will look at the Feature Selective Validation (FSV) method.
- Originally developed to overcome some of the limitations with statistical techniques and the subjectivity of eyeballing.
- The next few slides will explain a little of what it is, how it works and what are the current challenges.

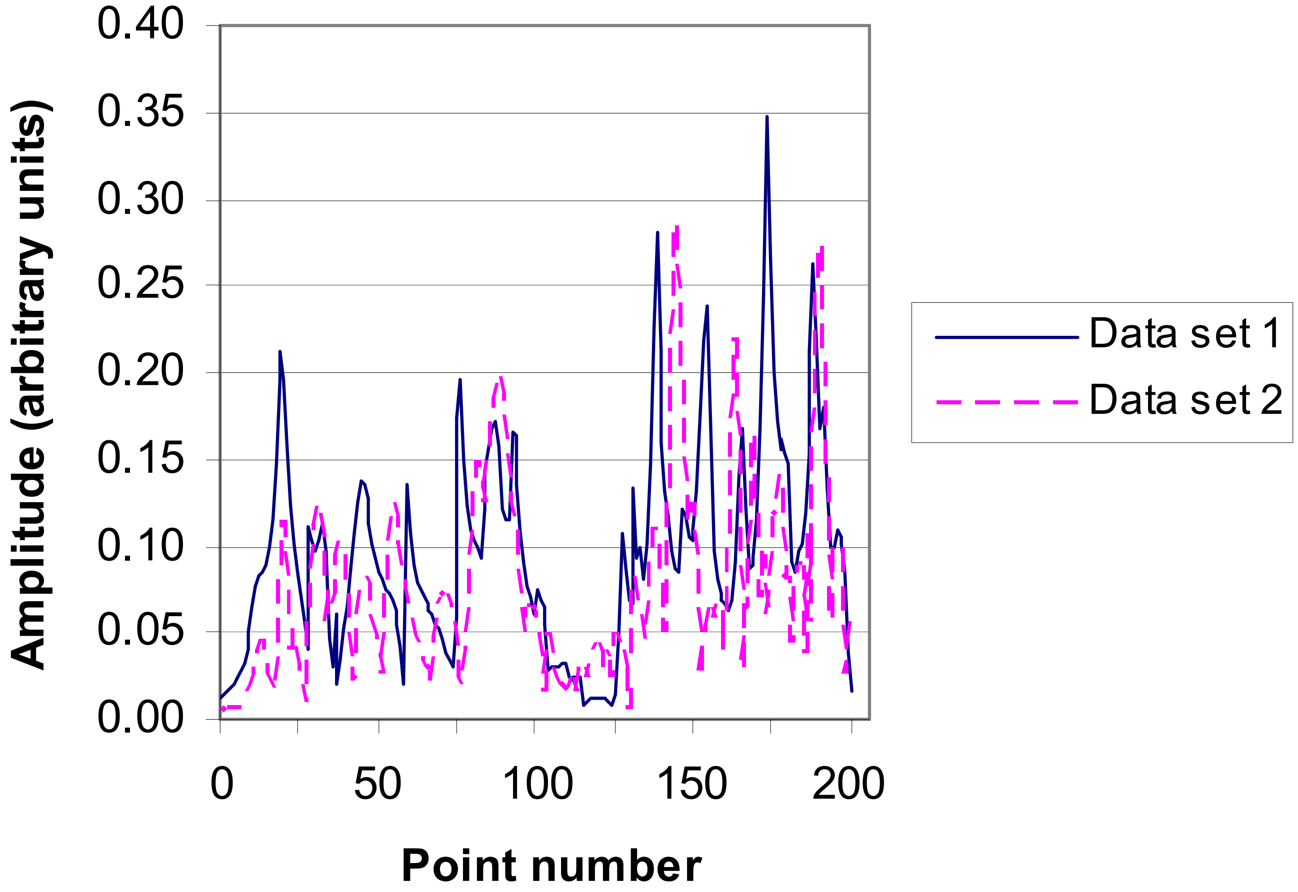
# FSV

- **Some design principles for validation**

1. Implementation of the validation technique should be simple
2. The technique should be computationally straightforward
3. The technique should mirror human perceptions and be largely intuitive
4. The method should not be limited to data from a single application area
5. The technique should provide tiered diagnostic information
6. The comparison should be commutative.

# FSV

- Visually, do these show good or fair agreement?



# FSV

- It is highly likely that, in looking at the previous graph, you would have taken note of the envelope and the features, drawing your conclusion from a combination of these.
- FSV has
  - Amplitude Difference Measure (ADM)
  - Feature Difference Measure (FDM)
  - Combining into a single goodness of fit measure
    - Global Difference Measure (GDM)

# FSV

- One objective was for the FSV method to 'emulate' a group of experts.
  - Need some way to calibrate against the group.
- Visual Rating Scale
  - Allows individuals or groups to visually assess a comparison to provide a benchmark using a common frame of reference.
  - Allows translation between FSV and visual basis.
  - Avoids limitations of other purely visual approaches to comparison

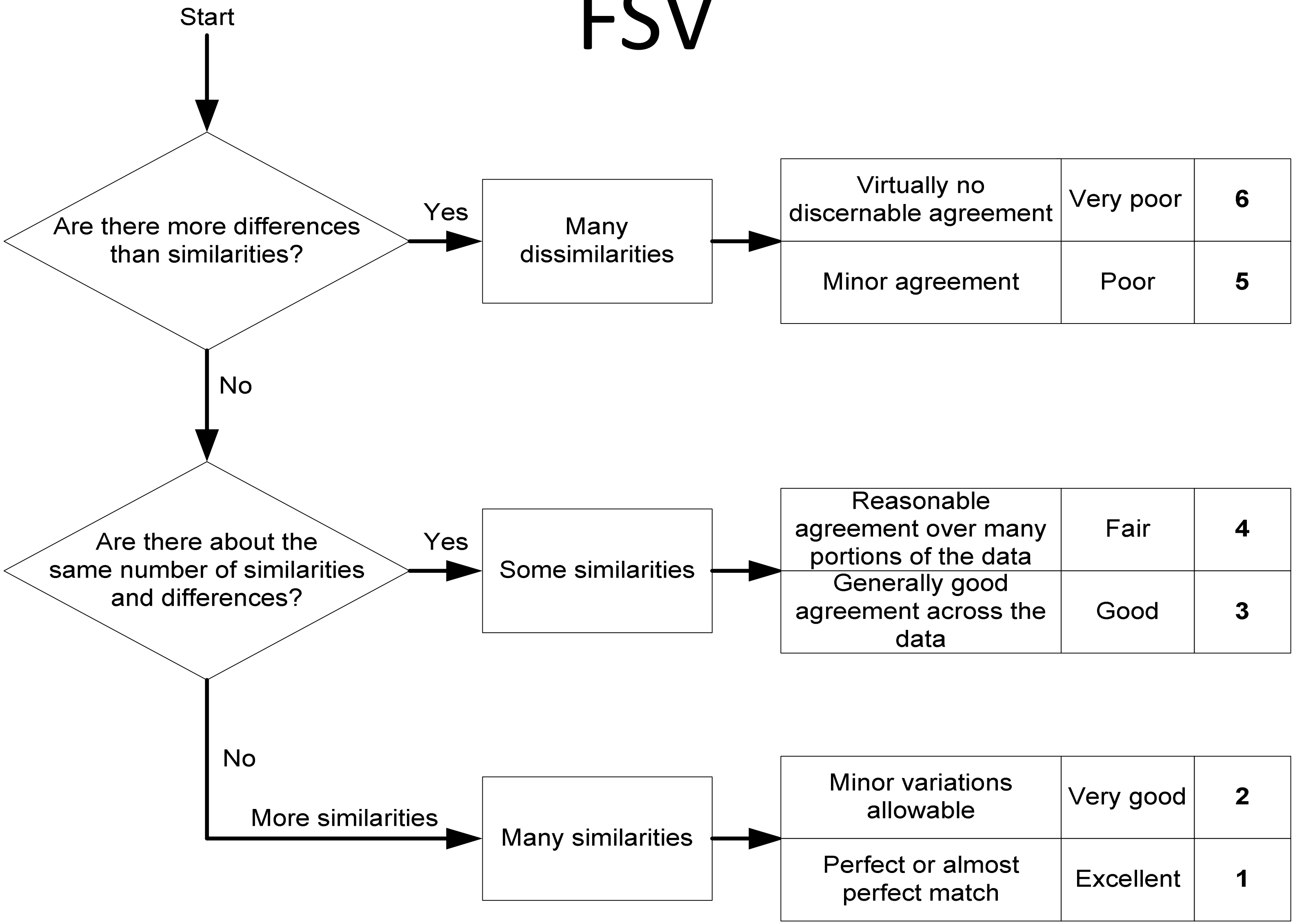
# FSV

- Visual Rating Scale
  - 6-point scale
  - Binary decision at each node
  - Provides outline definitions
  - Uses natural language descriptors
  - A mean value can be obtained from

$$Mean\ Rating = \sum_{i=1}^{6} i.P_i$$

» Where i is the category and $P_i$ is the proportion in that category

# FSV



Start
Are there more differences than similarities?
Yes
Many dissimilarities
Virtually no discernable agreement
Very poor
6
Minor agreement
Poor
5
No
Are there about the same number of similarities and differences?
Yes
Some similarities
Reasonable agreement over many portions of the data
Fair
4
Generally good agreement across the data
Good
3
No
More similarities
Many similarities
Minor variations allowable
Very good
2
Perfect or almost perfect match
Excellent
1

# FSV

- Assumptions in implementing FSV
  - – Data sets contain different numbers of data points
  - – Data sets exist over different ranges of the ‘x-axis’
  - – Values may be non-coincident over the ‘x-axis’

  - – FSV is “domain agnostic”
  - – FSV is insensitive to the order of comparison

# FSV

- The following is a very short description of the FSV method.

1. After taking the overlapping portion of the two data sets and interpolating them, if necessary, so that they have coincident x-axis locations, the data is Fourier Transformed.
2. Both data sets are low-, band- and high- pass filtered. The low pass gives offset information (aka DC), the band-pass gives trend information (aka Lo), the high-pass gives the feature information (aka Hi).

# FSV

These six elements (DC, Lo and Hi for the two data sets) are inverse transformed.

4. The Amplitude Difference Measure (ADM) is constructed from:

# FSV

$$ADM(n) = \left|\frac{\alpha}{\beta}\right| + \left|\frac{\chi}{\delta}\right| \exp\left\{\left|\frac{\chi}{\delta}\right|\right\}$$

$$\alpha = \left(\left|\mathrm{Lo}_1(n)\right| - \left|\mathrm{Lo}_2(n)\right|\right)$$

$$\chi = \left(\left|\mathrm{DC}_1(n)\right| - \left|\mathrm{DC}_2(n)\right|\right)$$

$$\beta = \frac{1}{N}\sum_{i=1}^{N}\left[\left(\left|\mathrm{Lo}_1(i)\right| + \left|\mathrm{Lo}_2(i)\right|\right)\right]$$

$$\delta = \frac{1}{N}\sum_{i=1}^{N}\left[\left(\left|\mathrm{DC}_1(i)\right| + \left|\mathrm{DC}_2(i)\right|\right)\right]$$

# FSV

- The Feature Difference Measure is constructed from:

$$FDM(f) = 2\left(\left|FDM_1(f) + FDM_2(f) + FDM_3(f)\right|\right)$$

# FSV

- Where

$$FDM_1(f) = \frac{\left|\mathrm{Lo}_1{}'(f)\right| - \left|\mathrm{Lo}_2{}'(f)\right|}{\frac{2}{N}\sum_{i=1}^{N}\left[\left(\left|\mathrm{Lo}_1{}'(i)\right| + \left|\mathrm{Lo}_2{}'(i)\right|\right)\right]}$$

$$FDM_2(f) = \frac{\left|\mathrm{Hi}_1{}'(f)\right| - \left|\mathrm{Hi}_2{}'(f)\right|}{\frac{6}{N}\sum_{i=1}^{N}\left[\left(\left|\mathrm{Hi}_1{}'(i)\right| + \left|\mathrm{Hi}_2{}'(i)\right|\right)\right]}$$

$$FDM_3(f) = \frac{\left|\mathrm{Hi}_1{}''(f)\right| - \left|\mathrm{Hi}_2{}''(f)\right|}{\frac{7.2}{N}\sum_{i=1}^{N}\left[\left(\left|\mathrm{Hi}_1{}''(i)\right| + \left|\mathrm{Hi}_2{}''(i)\right|\right)\right]}$$

# FSV

- The Global Difference Measure (GDM) is given by:

$$GDM(f) = \sqrt{ADM(f)^2 + FDM(f)^2}$$

- Single figure ‘goodness-of-fit’ values are obtained by taking a mean value of the ADM, FDM and GDM.

# FSV

- Values can be related to natural language descriptors:

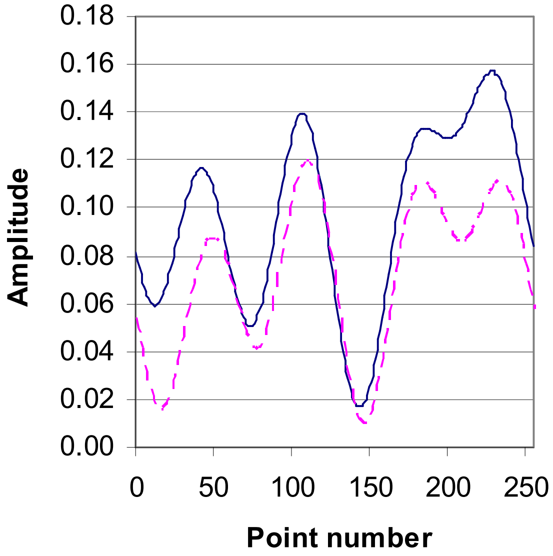
| FSV value (quantitative) | FSV interpretation (qualitative) |
|---|---|
| Less than 0.1 | Excellent |
| Between 0.1 and 0.2 | Very good |
| Between 0.2 and 0.4 | Good |
| Between 0.4 and 0.8 | Fair |
| Between 0.8 and 1.6 | Poor |
| Greater than 1.6 | Very poor |

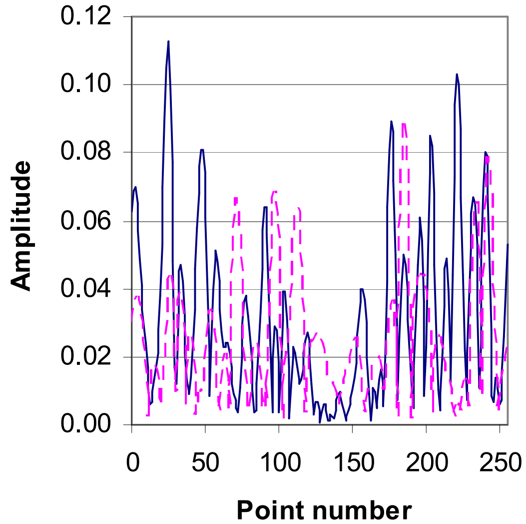
# FSV

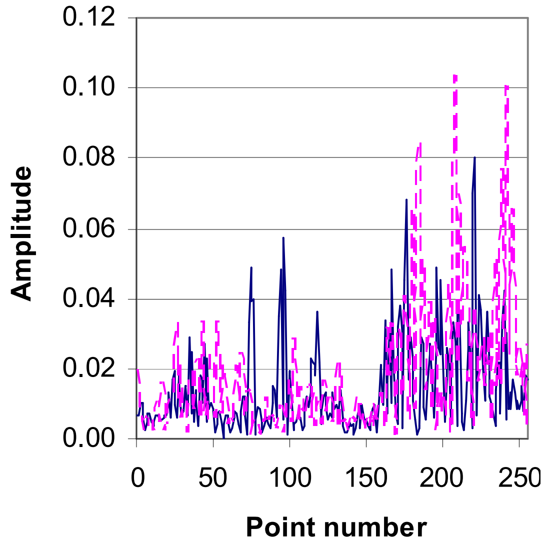
- Note: Natural language descriptors are there just to help in the communication of the FSV results and the visual assessment.
  - They are not prescriptive definitions of relative quality.
- Confidence histograms help relate FSV to group opinion as well as help interpret the FSV results.

# FSV

- Data for comparison
  - 'DC'  - Lo  - Hi

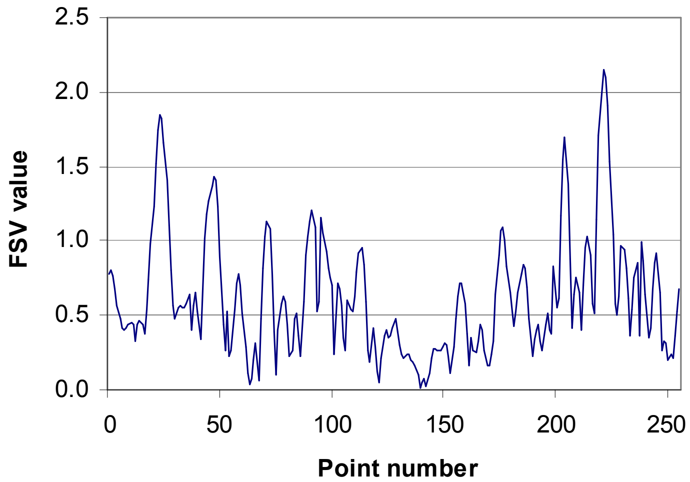


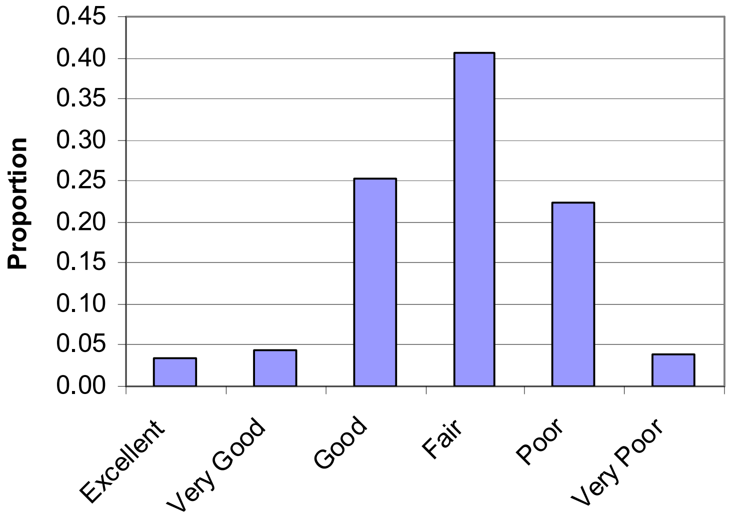



# FSV

- ADM

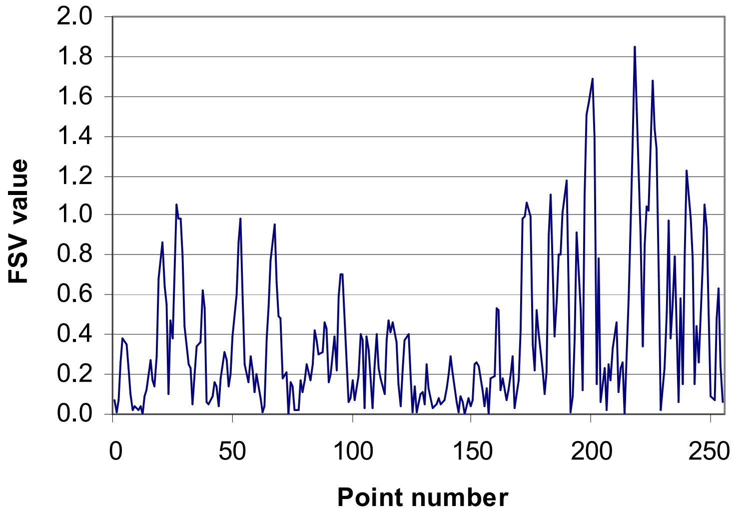


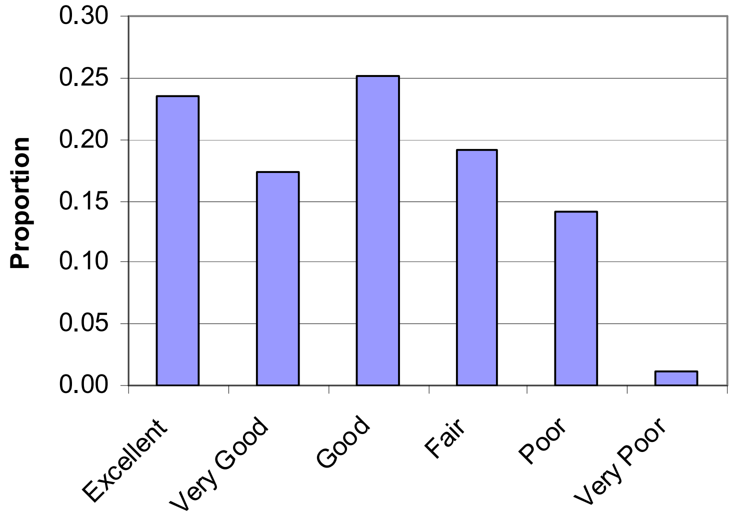




- Mean value = 0.62

# FSV

- FDM

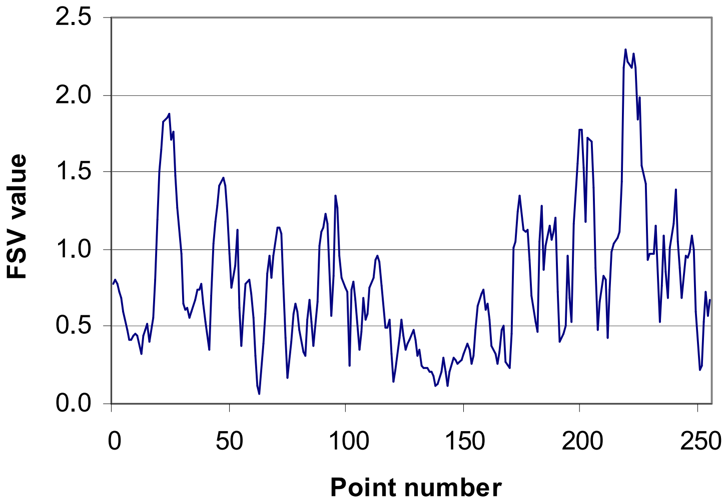


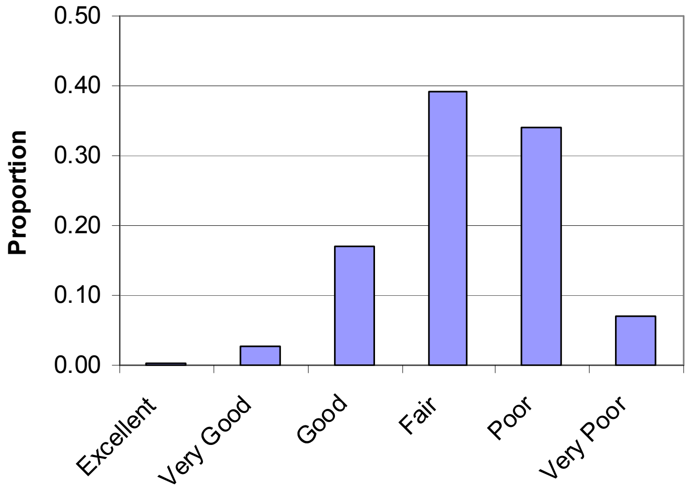




- Mean value = 0.39

# FSV

- GDM




- Mean value = 0.8

# FSV

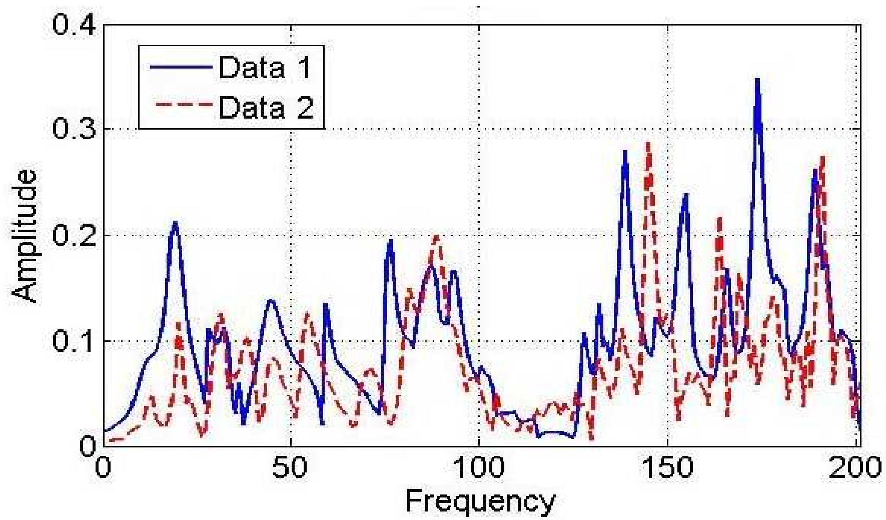
- The confidence histograms show variation in both shape and 'skew'
- Grade and Spread helpful in further interpretation
- Helpful in weighting ADM and FDM if required

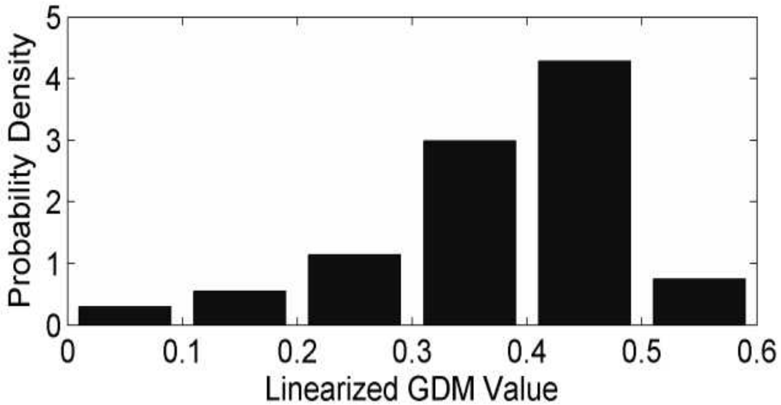
# FSV Developments - PDFs

- The original approach used six ‘bins’.
- “Excellent” etc. can be confusing
  - E.g. it may have a different meaning for EMC or microwave engineers.
  - So, what benefit might there be to using a continuous distribution function rather than a histogram?
    - More refined comparison
    - The use of non-parametric statistics

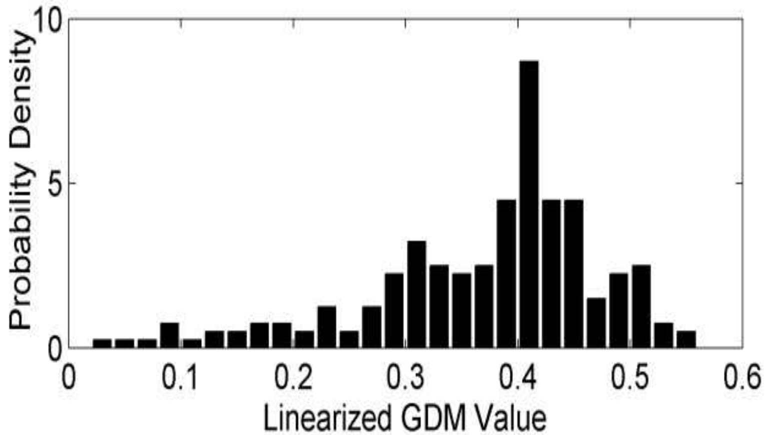
# Estimate of The Probability Density Functions

- Histogram difficulty




6 bins




30 bins

# PDFs

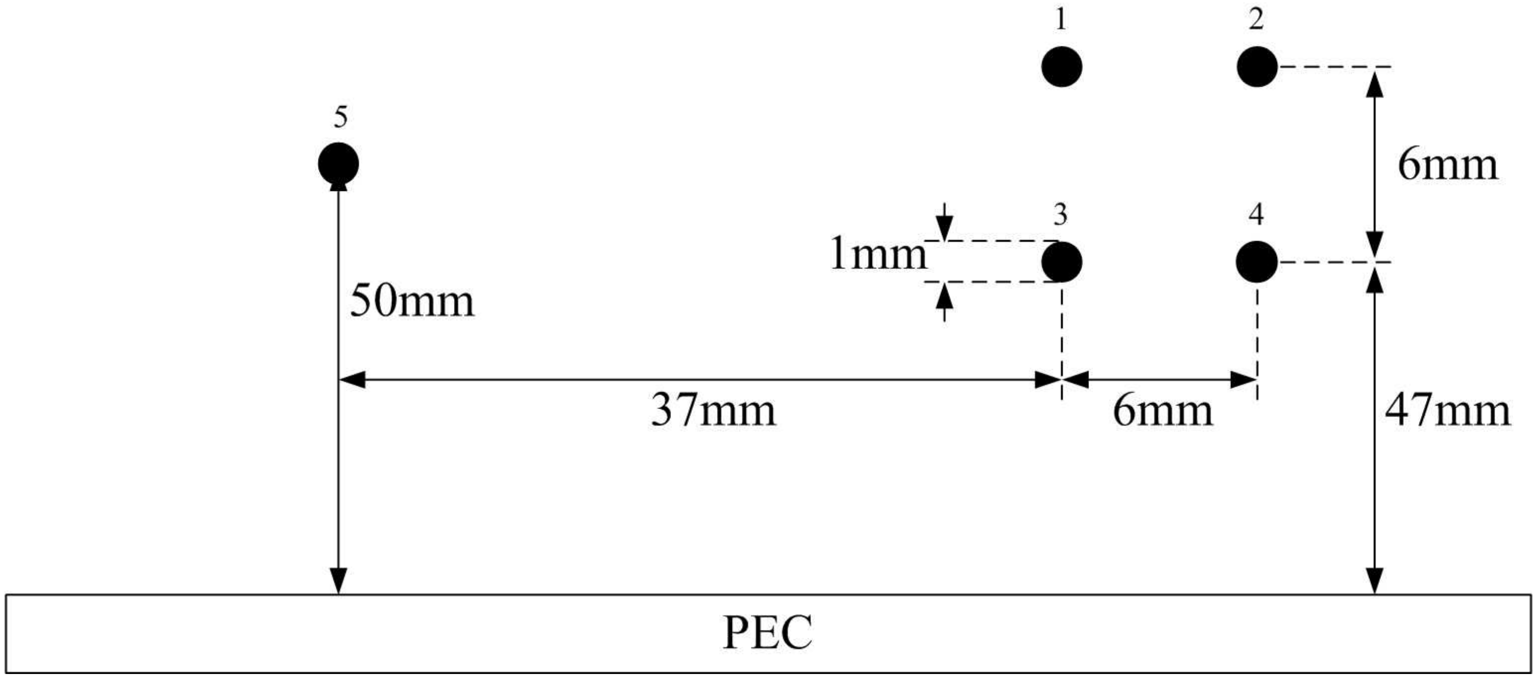
- Simple way is to generate cumulative density function and then apply a central difference approach to get the probability density function.

$$\hat{f}(x) = \frac{1}{nh}\sum_{i=1}^{n} K(\frac{x - x_i}{h})$$

- Gaussian kernel estimator gives smoother PDFs

$$K_{\text{Gaussian}}(u) = \begin{cases} (2\pi)^{-\frac{1}{2}} \mathrm{e}^{-\frac{u^2}{2}}, \ \text{-1<}u\text{<1}, \\ 0, \ \text{otherwise.} \end{cases}$$

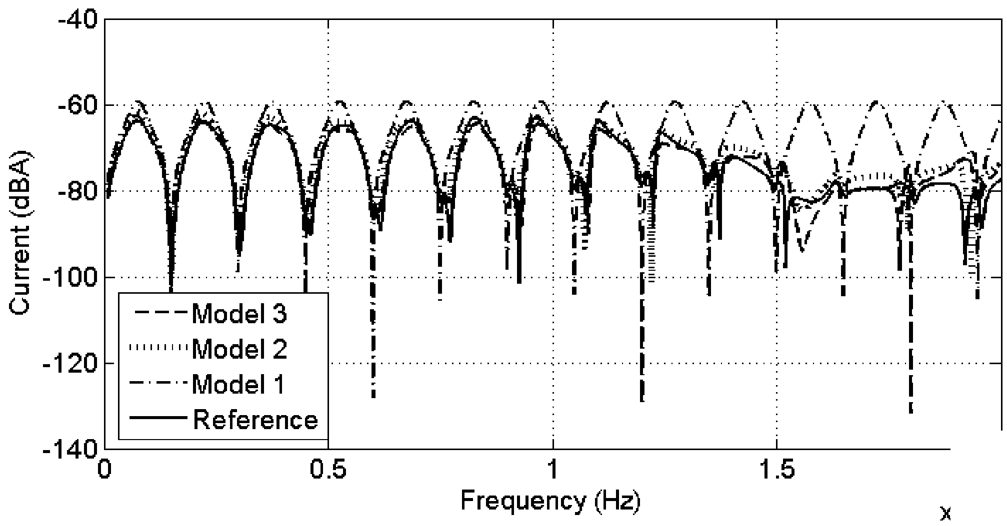
# PDF example - Model Optimization

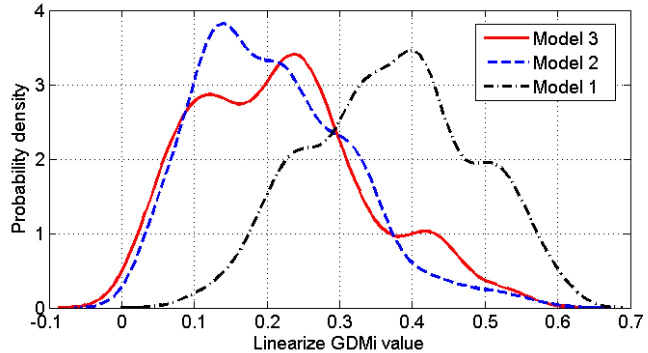



**Model 1:** equivalent circuit model
**Model 2:** simplified full-wave model
**Model 3:** further simplifying model 2
**Reference:** very subtle full-wave model

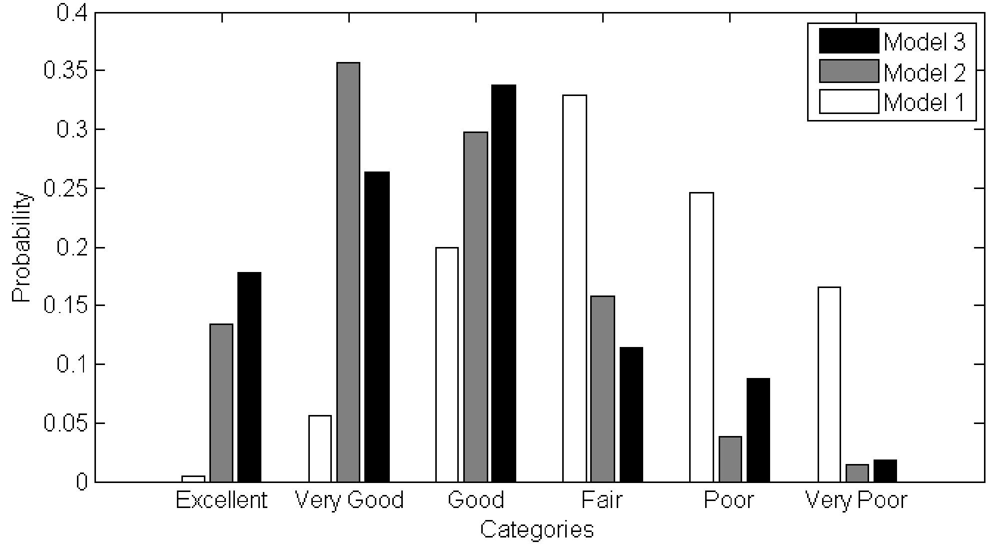
# PDF example - Model Optimization

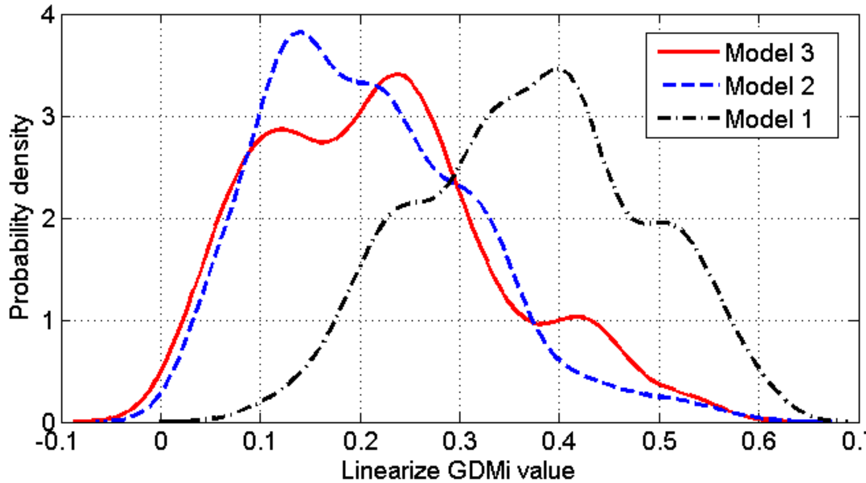
- near end crosstalk current of conductor 4.



# PDF example - Model Optimization

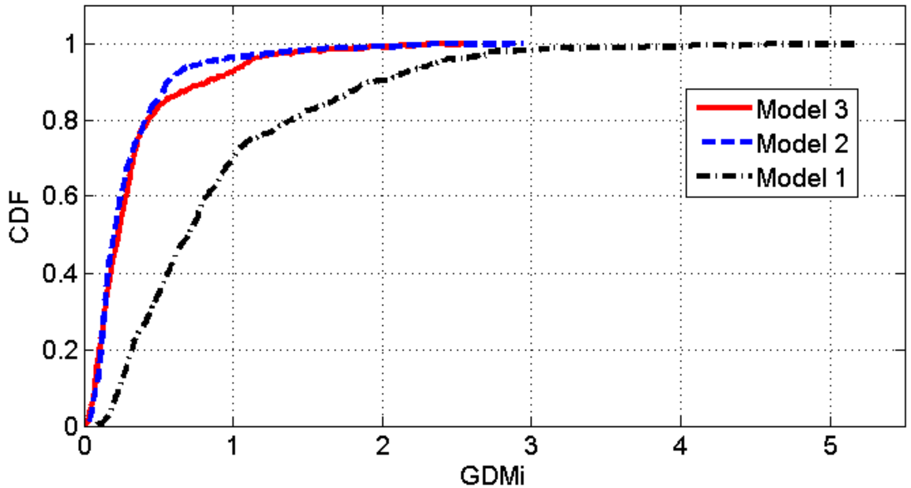


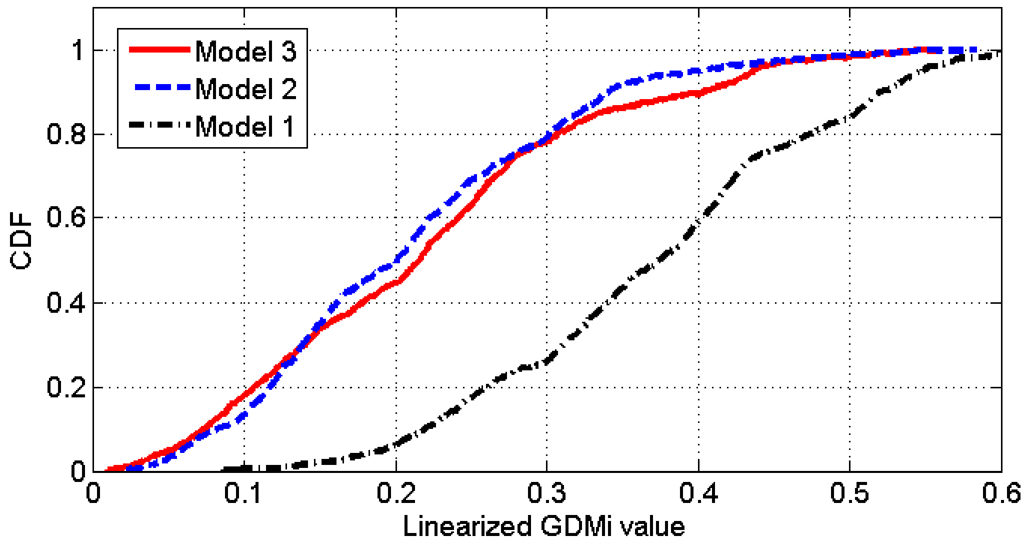



# PDF example - Model Optimization

- The Kolmogorov-Smirnov test (KS-test) aims to determine if the distributions of two datasets differ significantly.
  - **D value** the maximum vertical deviation between cumulative distribution function curves
  - **P value** significance level
- The KS-test is adopted because
  - The KS-test is a non-parametric test, so it has the advantage of making no assumption on the distribution of data;
  - The results of the test is not affected by scale changing procedures: the KS-test is a robust test that depends only on the relative discrepancy of distribution.

# PDF example - Model Optimization



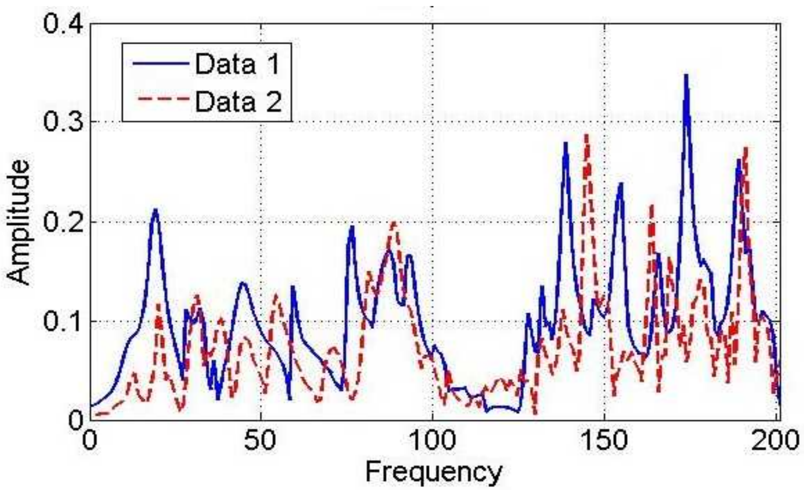



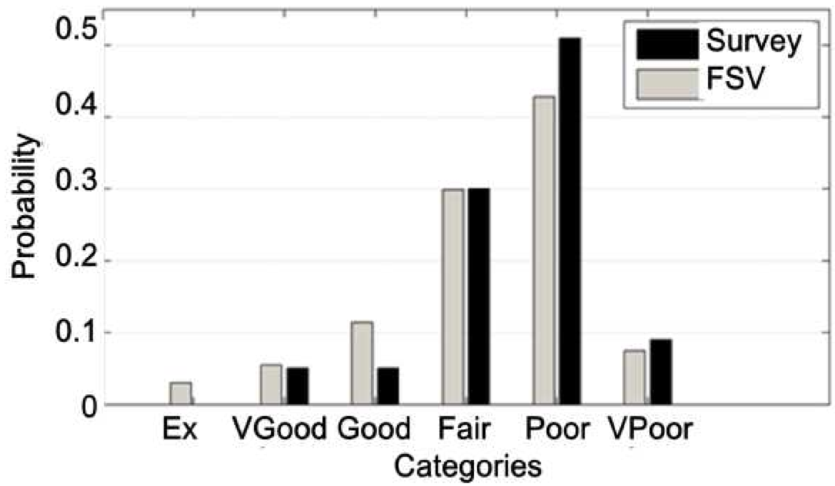
# PDF example - Model Optimization

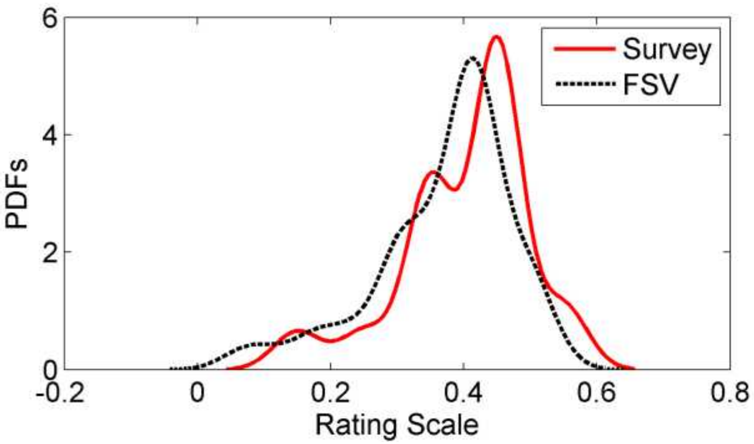
- The KS-test results indicate that
  - The difference between model 2 and model 3 is not significant.
  - The simplification made on model 1 has had significant influence on the validity of the simulation.

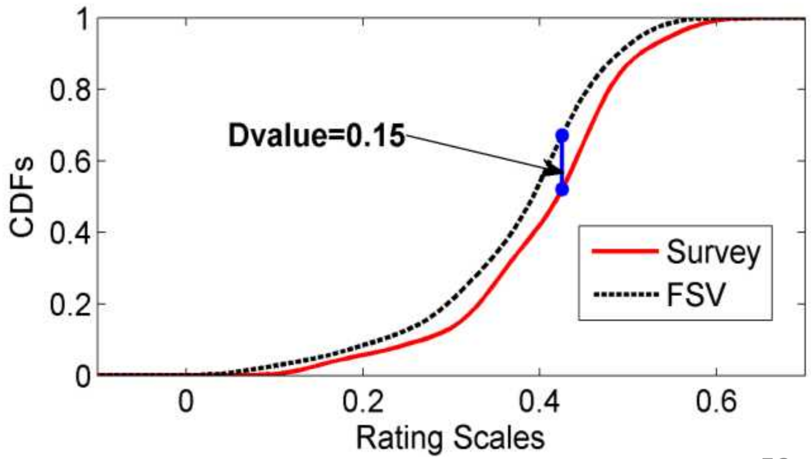
| Models | KS-test<br>D value | FSV (GDMtot) |
|---|---|---|
| Model 2, Model 3 | 0.07 | 0.30, 0.34 |
| Model 1, Model 3 | 0.52 | 0.88, 0.34 |
| Model 1, Model 2 | 0.54 | 0.88, 0.30 |

# PDF example – FSV verification



# PDF example – FSV verification

- The critical value of statistic D for different significance level can be decided by

$$D_{Critical} = k \cdot \sqrt{\left(N_1 + N_2\right) / \left(N_1 \cdot N_2\right)}$$

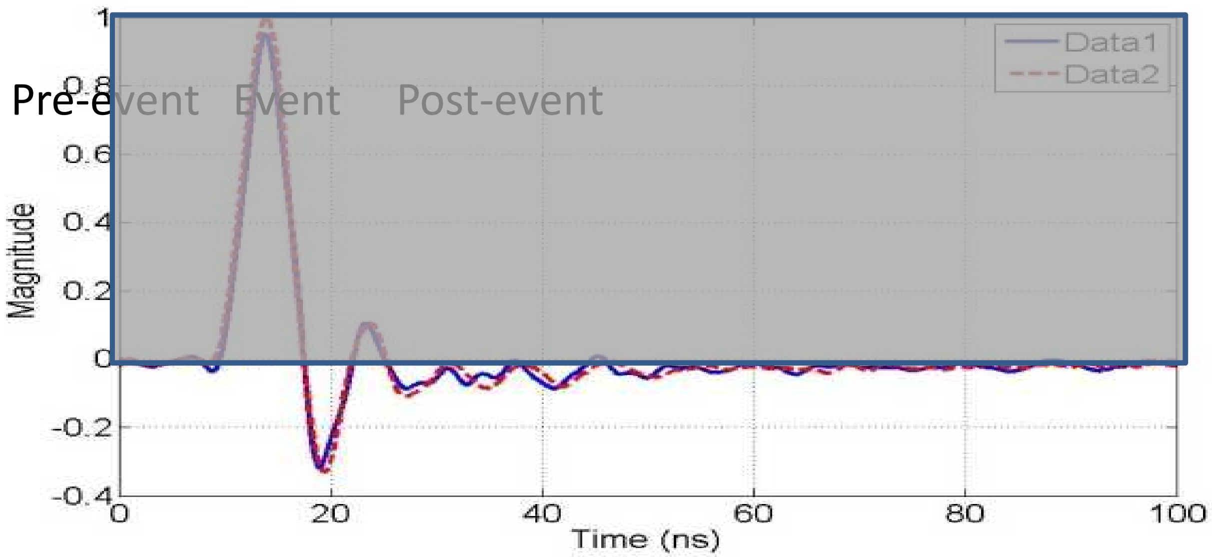
  – where $N_1$ and $N_2$ are the length of datasets under comparison. For 95% confidence, *k* is 1.36, for 90% confidence, *k* is 1.22. $N_1 = N_2 = 100$

- Here the $D_{Critical}$ for 90% confidence is 0.17

  In this case, the null hypothesis is accepted.

# FSV Developments – Transients

- Transient-type phenomena can be difficult.
  - Particularly with variability in periods.
  - Negative going portion

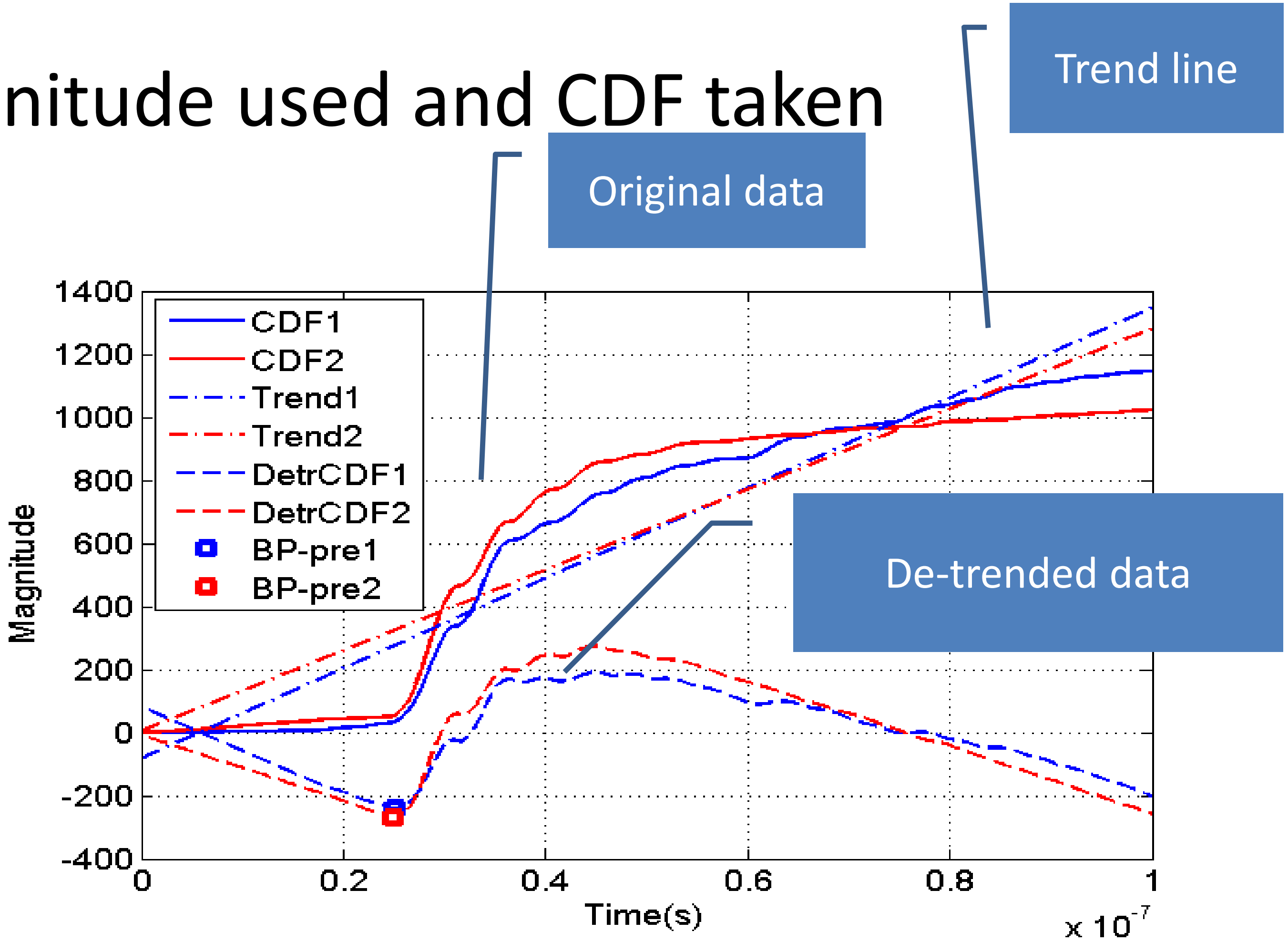


# Transients

- Negative going data
  - Translate to the positive half plane
    - Does not appear to affect results
  - Needs further investigation
- Weight individual regions separately
  - Pre-event = 5%
  - Event = 70%
  - Post-event = 25%
  - Again, for further study
- Dynamically allocate region boundaries

# Transients – region allocation

- Magnitude used and CDF taken

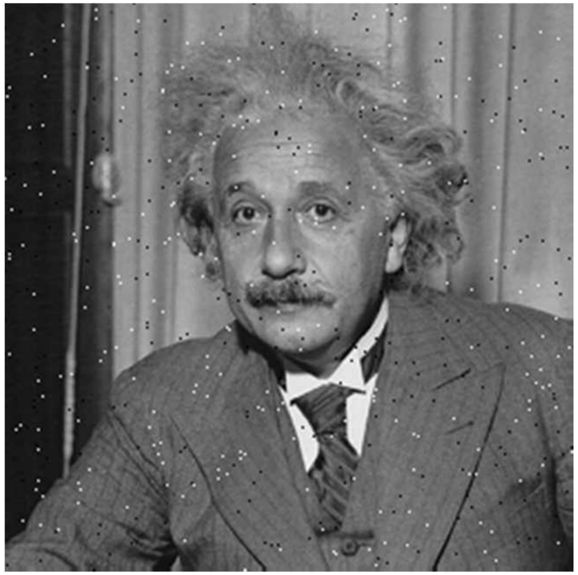


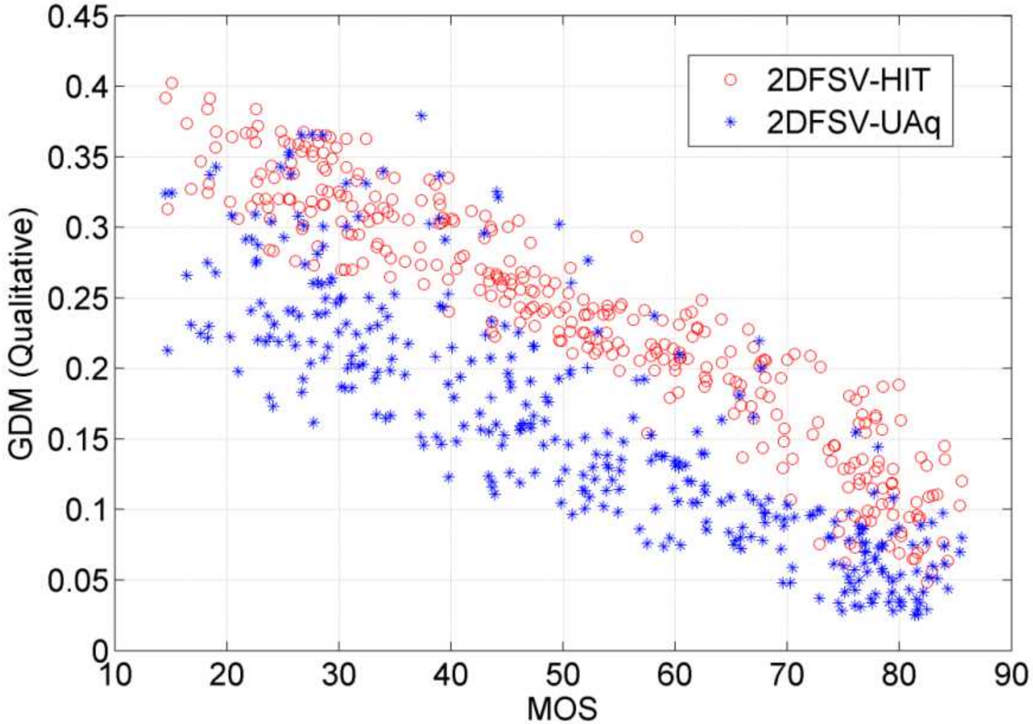
# Multidimensional FSV

- Still an area of active research
- Many problems have many degrees of freedom
- Quantitative comparison is challenging
  - No ‘visual’ verification … fly-by-instrument
  - Requires geometrically ‘shaped’ filters
  - Multidimensional Fourier transforms
  - Each dimension will not be equally weighted
    - Computationally challenging

# Thinking beyond engineering

- Image quality assessment
  - Comparing FSV comparison with the LIVE database's Mean Opinion Score (MOS)





# A last word

This talk has overviewed aspects of two key research themes related to:

- Physical infrastructure
- Data analysis

Thank you

# Any questions